nerve given in the third column, both the commencement and the culmination of the initial change are retarded, the propagation rate in this nerve at a temperature of 6° C. being slowed to 6 metres per second. A comparison of the fourth and fifth columns shows the retardation in the anodic as compared with the acceleration in the cathodic extrapolar region. Finally the time relations and the relative E.M.F. of the prolonged effect present in the instances given in the second and fourth columns may be compared with those of the initial change present in all the examples. It will be seen that the change producing the prolonged tail of the photographic record is one which differs from that producing the initial spike in the following important particulars: it develops slowly, taking from 0·006 to 0·01 second to culminate, its maximum E.M.F. is only one-tenth of that of the initial change, and it subsides slowly. It is not present in the instances given in columns I, III, and V.

In a more extended communication the authors hope to bring forward other features of the response of nerve, particularly the characters exhibited by the records of the changes produced by a series of stimuli and of those produced during reflex discharge of the central nervous system.

"On the Magnetic Susceptibility of Liquid Oxygen." By J. A. Fleming, M.A., D.Sc., F.R.S., Professor of Electrical Engineering in University College, London, and James Dewar, M.A., LL.D., F.R.S., Fullerian Professor of Chemistry in the Royal Institution, London, &c. Received May 9,—Read May 12, 1898.

In a previous communication* we have described the initial investigations made by us to determine directly the numerical value of the magnetic permeability of liquid oxygen, and we there indicated that we hoped before long to present to the Royal Society the results of other experiments made by a different physical method which we anticipated would enable us to state whether liquid oxygen has a constant magnetic susceptibility, or whether, like a ferromagnetic substance, its magnetic susceptibility alters when subjected to different magnetic forces.

We have recently obtained results which, though limited to a certain range of force, we think afford fairly trustworthy values of the magnetic susceptibility of liquid oxygen under magnetising forces varying from 500 to 2500 C.G.S. units, and place them therefore on record.

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* 'Roy. Soc. Proc.,' 1896, vol. 60, p. 283, "On the Magnetic Permeability of Liquid Oxygen and Liquid Air."

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The method used by us in these last experiments depends on the well-known fact that if a body, either paramagnetic or diamagnetic, is placed in a magnetic field of variable strength, it is subjected to a mechanical force tending to displace it in the direction in which the field varies most rapidly.

If the susceptibility of the body is so small that it does not sensibly disturb the distribution of the field, the measurement of this mechanical force may be made to furnish a knowledge of the absolute value of the magnetic susceptibility.

The necessary conditicns are, however, that the volume (V) of the body must be of such small magnitude relatively to the form of the field that its magnetisation is not sensibly different from that which it would obtain if immersed in a uniform field, and also that the magnetic susceptibility (k) of the substance must be of small absolute value. Under these circumstances, if f is the mechanical force (reckoned in dynes) acting on the body, and H is the strength of the field at its centre, then the force in the direction x is given by the equation

$$f = k\mathrm{VH}\frac{d\mathrm{H}}{dx}.$$

The value k thus determined is a difference value, that is, it is equal to the difference between the susceptibility of the body and that of the medium in which it is immersed. Hence if one and the same body is placed in the same divergent field, but alternately surrounded by different media, the difference in the apparent susceptibilities of the body in the two cases will give us the difference of the true susceptibilities of the media. The experimental method employed by us consisted, therefore, in determining the forces acting on a small sphere of known susceptibility when suspended first in air, and next in liquid oxygen, and hence deducing the difference of the susceptibility of liquid oxygen and air, and therefore the absolute value of the susceptibility of liquid oxygen, knowing that of air.

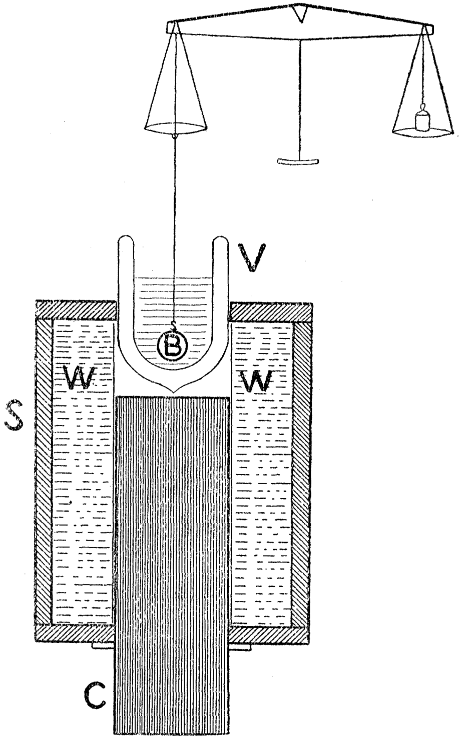
The first step was the construction of an electro-magnet capable of producing the required field. From the above-named conditions of success it will be seen that since the volume and susceptibility to be measured are both small, it is essential that the magnetic field shall not only be large but must vary very rapidly, or else the forces to be measured will be small.

An electro-magnet giving the required field was therefore designed as follows:—

The exciting bobbin consists of a single coil of double cotton-covered copper wire, No. 14 S.W.G. in size.

The coil is 30 cm. long, 18·5 cm. in outside diameter, and the aperture in the coil 9·5 cm. in diameter. The total weight of double cotton-covered copper wire on the bobbin is 71 lbs., and the total length of wire is roughly about 3300 feet. The total number of turns of wire on the bobbin is 2478. The wire is capable of carrying 12 or 14 amperes for considerable periods of time without dangerous heating. The total resistance of the wire is very nearly 5·5 ohms at 20° C.

This bobbin of wire is enclosed in a cylinder of mild steel of the same height as the bobbin, the walls of which are 2·5 cm. thick. This cylinder has movable circular end plates of steel 2·5 cm. in thickness fitting it, and in these plates are circular holes 9 cm. in diameter. A soft steel core was also provided, 37 cm. in length and 9 cm. in diameter, and having steel studs screwed into it so that the core could be held in he position shown in the diagram. The end surface of the inner core was 7·5 cm. below the upper surface of the wire coil. The steel used is high permeability magnet steel.



V, vacuum vessel; B, ball weighed; W, wire windings of magnet; S, C, steel shell and magnet core.

On passing a current through the magnet coils a magnetic field is created in the space just above the upper end of the inner steel core, which is very divergent, and which is not only strong, but varies very rapidly in an axial direction.

This magnet was placed underneath a shelf on which stood a very sensitive short-beam chemical balance capable of weighing to one-tenth of a milligram. From one pan depended a fine wire passing through a hole in the balance case and shelf, and served to suspend a ball just within the field of the magnet.

If the ball was counterpoised by weights and the magnet then excited, the ball was subjected to an upward or downward force which either decreased or increased its apparent weight, according as it was diamagnetic or paramagnetic. If W is the gain or loss in weight on exciting the magnet, V the volume of the ball, H the strength of the field at its centre, and $d\mathrm{H}/dx$ the rate of change of the field in a vertical direction, then the equation

$$981\mathrm{W} = k_1\mathrm{VH}\frac{d\mathrm{H}}{dx}$$

gives us the value of the apparent magnetic susceptibility (k_1) in air of the body weighed.

In order to apply the method we require to know the value of the field H at different parts along the vertical axis of the magnet and also the value of the field for various exciting currents.

A careful preliminary investigation on this point was therefore made. Constant currents varying from 1 to 12 or 14 amperes were passed through the magnet coils and by means of a small secondary coil attached to a calibrated ballistic galvanometer the field strength at various points in the vertical central axis of the magnet was measured. These measurements extended from close contact with the magnet core to a point about 10 cm. above the end surface of the recessed polar end of the inner steel core.

The distance in centimetres of any point from the end polar surface of the inner steel core is denoted by x, this measurement being made as exactly as possible along the central vertical axis of the magnet. The strength of the field at this point in C.G.S. units is denoted by H, and the space rate of change in the x direction by $d\mathrm{H}/dx$.

The following tables give the exciting currents (A) in amperes measured by a Weston ammeter, No. 3134, and the values of x and H.

The value of $d\mathrm{H}/dx$ at any point can be at once determined from the curve of H in terms of x.

Table I.—Magnetisation Curves of Tubular Electromagnet, the Induction Density or Field being measured at a point x centimetres from the Pole Face on the Axial Line.

Exciting current by Weston ammeter, No. 3134.	True current in amperes. A.	Induction density (H) at various distances x from the pole.		
		x = 0·15 cm.	x = 2·70 cm.	x = 5·25 cm.
15	15·15	4374	—	—
14	14·141	4200	—	—
13·9	14·040	—	3269	—
13	13·127	4054	3194	—
12	12·094	3848	3070	2002·5
11	11·124	3648	2888	1897
10	10·075	3407	2712	1782·5
9	9·082	3194	2543	1682
8	8·059	3014	2310	1557
7	7.059	2764	2153	1418·5
6	6·020	2504	1957	1273
5	5·015	2220	1740	1139
4	3·968	1884	1459	955·5
3	2·994	1481	1161	749
2	1·958	992	767	491·5

The induction density or field along the axial line was also measured for two constant excitations corresponding to currents of 12·094 and 6·020 amperes at various distances along the axial line, and the results are given in Table II.

The results in Tables I and II were then set out carefully in a curve, and from these curves an interpolation table constructed, showing the axial field at various points on the axis for different exciting currents, and these values are given in Table III.

Having calibrated the magnet, the following objects were provided to be used as bodies to weigh in the field, viz.:—

(1) A silver ball, (2) a rather smaller copper ball, (3) several hollow glass balls containing a little mercury, and (4) a bismuth ball.

In order to test the method and obtain confidence in the results, we made a number of preliminary measurements on the magnetic susceptibility of water, solutions of manganese sulphate, and ferrous sulphate of known densities.

These experiments were made by weighing the silver ball or hollow glass ball when immersed in these liquids contained in a beaker placed in the field cavity of the magnet.

Five weighings were always made—

(1) The weight of the ball in air, magnet not excited.

(2) The apparent weight of the ball in air, magnet excited.

(3) The apparent weight of the ball in water, magnet not excited.

(4) The apparent weight of the ball in the solution used, magnet not excited.

(5) The apparent weight of the ball in the liquid, the magnet being excited with a known current, and the position of the ball in the field accurately known.

From these weighings we obtain all the required information. For from (1) and (3) we obtain the volume of the ball, and from (1), (2), and (3) the magnetic susceptibility of the ball, and from (4) and (5) the magnetic susceptibility of the liquid.

The sphere used as a testing substance was suspended by a long fine platinum or gold wire from one pan of the balance. A small beaker filled with water or the salts solution under test was placed over the pole of this magnet and the sphere suspended in it.

In some cases when using strong exciting currents we found it

Table II.—Induction Densities (H) of Field of Tubular Electromagnet at various distances x along the Axial Line.

Distance from pole face = x cm.	Field = H in C.G.S. units.	
	For 6·020 amperes.	For 12·094 amperes.
0·15	2485·5	3853
0·58	2475·5	3825
1·01	2404	3711
1·44	2307·5	3582
1·87	2196·5	3419
2·30	2068	3225
2·73	1935	3016
3·16	1794	2830
3·59	1666	2624
4·02	1557	2453
4·45	1455·5	2291
4·88	1346	2128
5·31	1253	1960
5·74	1151·5	1820
6·17	1052	1666
6·60	965·5	1521
7·03	867	1385
7·46	770	1260
7·89	680	1099
8·32	596	955
8·75	509·5	805
9·10	425	681
9·61	356·5	564
10·04	294·5	462
10·47	231·4	368
10·91	189·9	289
11·33	142·1	228
11·76	114·2	175

Table III.—Summary of Results of Field Measurements of Axial Field of Tubular Electromagnet.

Current by Weston ammeter, No. 3134.	Distance from pole face on axial line.			Ratios of induction density or field H to field corresponding to 6·0 or 12·0 true amperes.		
	0·15 cm.	2·70 cm.	5·25 cm.	0·15 cm.	2·70 cm.	5·25 cm.
0	0	0	0	0	0	0
2	994	762	492	0·3989	0·3908	0·3862
3	1476	1148	742	0·5923	0·5887	0·5825
4	1778	1460	952	0·7135	0·7487	0·7473
5	2220	1726	1128	0·8908	0·8852	0·8854
6	2492	1950	1274	1·0000	1·0000	1·0000
7	2760	2158	1422	1·1075	1·1066	1·1161
8	2996	2346	1556	1·2022	1·2031	1·2213
9	3226	2534	1678	1·2945	1·2995	1·3171
9	3226	2534	1678	0·8402	0·8363	0·8466
10	3438	2712	1782	0·8954	0·8950	0·8991
11	3650	2880	1890	0·9506	0·9504	0·9536
12	3840	3030	1982	1·0000	1·0000	1·0000
13	4028	3178	2080	1·0490	1·0488	1·0494
14	4208	3320	2168	1·0959	1·0957	1·0939
14·5	4292	3390	2210	1·1177	1·1188	1·1153
15	4374	3460	2254	1·1391	1·1420	1·1372

necessary to pack round the beaker of liquid with crushed ice in order to keep the temperature of the water or solution from being raised by radiation of heat from the magnet coils. Any rise of temperature in the liquid under test, by causing variation in density, introduces a difficulty in obtaining exact and comparable weighings of the ball.

The position of the ball in the magnetic field was very carefully adjusted, so that the centre of the ball was as nearly as possible on the axial line of the magnet. The distance of the centre of the ball from the end of the magnet core was also measured with as much accuracy as possible when the balance was lifted off its supports, and yet the balance index was in the zero position.

The distance from the pole face measured in centimetres is called the *distance from the pole* in the following tables. Corresponding to this distance (x) we know from the preliminary experiments and the results given in Tables I, II, and III the strength of the magnetic field (H) and its axial rate of variation dH/dx.

The dimensions and weights of the balls used were as follows:—

Ball made of	Weight in grams.	Diameter in cm.	Density.	Volume in c.c. at 15° C.	Volume in c.c. at −182° C.	Mean coefficient of cubical expansion between 0° C. and −182° C.
Silver	132·010	2·90	10·334	12·775	12·654	0·0000518
Copper	37·610	2·00	9·92	4·226	4·190	0·0000427
Bismuth	62·220	2·27	9·836	6·326	6·287	0·0000320
Glass ball containing mercury, No. 1 ..	18·663	2·32	—	6·539	6·513	0·0000200
Glass ball containing mercury, No. 2 ..	3·400	1·40	—	1·462	1·456	„
Glass ball containing mercury, No. 3 ..	32·500	2·68	—	10·343	10·340	„
Glass ball containing mercury, No. 4 ..	5·95	1·03	—	0·588	0·586	„

In each case a measurement was made of the magnetic susceptibility in air of the ball used, by weighing it in a known magnetic field and observing the loss or gain in weight.

In this manner the following determinations were made:—

The Magnetic Susceptibility of the Silver Ball.

Weight of silver ball in air at 15° C. = 132·010 grams.
Weight of silver ball in water at 2° C. = 119·235 grams.
Volume of silver ball at 15° C. = 12·775 c.c.

	I.	II.	III.	IV.
Loss in weight in grams of silver ball when weighed in field = W......................	0·0287	0·0284	0·0142	0·0132
Exciting currents of magnet in amperes	12	12	6	6
Magnetic field in C.G.S. units = H......................	3320	2820	1798	2206
Field variation = dH/dx	426	459	308	258
Distance of centre of ball from pole in cm..................	1·96	3·18	3·18	1·83
Calculated apparent susceptibility = $k^1 10^{-6}$	1·56	1·68	1·97	1·78

The absolute magnetic susceptibility of air is $0·024 \times 10^{-6}$.

The mean apparent susceptibility of silver in air is therefore from the above figures equal to $-1{\cdot}75 \times 10^{-6}$, and the absolute value $k = -1{\cdot}73 \times 10^{-6}$.

E. Becquerel gives $-1{\cdot}74 \times 10^{-6}$ as his observed value for silver.

The Magnetic Susceptibility of the Bismuth Ball.

Weight of bismuth ball in air at 15° C. = 62·220 grams.
Volume of bismuth ball at 15° C. = 6·326 c.c.

	I.	II.	III.
Loss in weight in grams of bismuth ball when weighed in field = w ...	0·085	0·067	0·030
Exciting current of magnet in amperes	14·5	12	6
Magnetic field	2383	2135	1355
Field variation....................	415	372	236
Distance of centre of ball from pole = x in cm.....................	4·86	4·86	4·86
Calculated apparent susceptibility = $k^1 10^{-6}$	−13·4	−13·3	−14·6

The absolute magnetic susceptibility of air is $0{\cdot}024 \times 10^{-6}$. The mean apparent susceptibility of bismuth in air is, therefore, from the above figures equal to $-13{\cdot}77 \times 10^{-6}$, and the absolute susceptibility $k = -13{\cdot}75 \times 10^{-6}$.

Recent values found by other observers are $-13{\cdot}4 \times 10^{-6}$ (P. Curie), and $-13{\cdot}3 \times 10^{-6}$ (L. Lombardi). Hence our own is in accordance with these.

The Magnetic Susceptibility of the Copper Ball.

Weight of copper ball in air at 15° C. = 37·610 grams.
Volume of copper ball in air at 15° C. = 4·226 c.c.

	I.	II.	III.	IV.
Gain in weight in grams of copper ball in field	0·009	0·005	0·0055	0·0035
Exciting currents of magnet in amperes	6	3	6	3
Magnetic field................	1220	709	518	298
Field variation	227	132	193	111
Distance of centre of ball from pole in cm.	5·46	5·46	8·72	8·72
Calculated apparent susceptibility = $k^1 10^{-6}$..............	+7·6	+12·5	+12·9	+28

The copper ball proved to be ferromagnetic, owing, no doubt, to traces of iron. We constructed a curve by which its susceptibility in various fields could be deduced from the above observations, but the only reason we employed it was because it seemed desirable to determine the absolute susceptibility of the liquid oxygen with bodies as far as possible different in susceptibility. Hence we selected silver, bismuth, and the above slightly ferromagnetic copper ball for the purpose.

The Magnetic Susceptibility of various Glass Balls partly filled with Mercury.

	No. 1 ball.	No. 2 ball.	No. 3 ball.	No. 4 ball (nearly full of mercury).
Gain or loss in weight in grams of ball when weighed in field	−0·001	This ball proved to be quite neutral in the strongest field we could produce	−0·0044	−0·0007
Exciting current of magnet in amperes	6	—	12	12
Magnetic field	1330	—	3180	2418
Field variation ...	231	—	474	391
Distance of centre of ball from pole of magnet in cm.	4·96	—	2·38	4·115
Calculated apparent susceptibility = $k^1 10^{-6}$....	−0·5	zero	−0·277	−1·23

We have, then, the following data for the glass balls:—

	No. 1 ball.	No. 2 ball.	No. 3 ball.	No. 4 ball.
Weight in grams...	18·663	3·400	32·500	5·95
Volume in c.c. at 15° C.	6·539	1·462	10·3427	0·5882
Diameter in cm. ...	2·32	1·40	2·68	1·03
Absolute magnetic susceptibility in vacuum.........	$-0·48 \times 10^{-6}$	$-0·024 \times 10^{-6}$	$-0·25 \times 10^{-6}$	$-1·21 \times 10^{-6}$

As a further check on the method we employed the above determinations of the susceptibilities of the silver and glass ball, No. 3, to obtain the value of the susceptibility of distilled water. The measurements were as follows:—

Magnetic Susceptibility of Water.

$$\text{I, with silver ball} \left\{\begin{array}{l}\text{susceptibility of ball} = -1{\cdot}73 \times 10^{-6}. \\ \text{volume of ball} = 12{\cdot}775 \text{ c.c.}\end{array}\right.$$

$$\text{II, with glass ball, No. 3} \left\{\begin{array}{l}\text{susceptibility of ball} = -0{\cdot}25 \times 10^{-6}. \\ \text{volume of ball} = 10{\cdot}3427 \text{ c.c.}\end{array}\right.$$

	I.	I.	II.
Gain or loss in weight of ball when weighed in field and in water	−0·0146 gram loss	−0·0163 loss	+0·0053 increase
Exciting currents of magnet in amperes	12	14·5	12
Magnetic field	2802	2848	3180
Field variation....................	456	465	474
Distance of centre of ball from pole of magnet in cm................	3·22	3·79	2·38
Apparent susceptibility of ball in water = $k^1 10^{-6}$................	−0·878	−0·945	+0·333

The absolute susceptibility of water is, therefore,

$$-(1{\cdot}73-0{\cdot}88)10^{-6} = -0{\cdot}85 \times 10^{-6}$$

and $-(1{\cdot}73-0{\cdot}94)10^{-6} = -0{\cdot}79 \times 10^{-6}$ from the experiments with the silver ball; and $-(0{\cdot}333 + 0{\cdot}253)10^{-6} = 0{\cdot}59 \times 10^{-6}$ from the experiments with the glass ball No. 3. The mean of these values gives $-0{\cdot}74 \times 10^{-6}$ as the absolute susceptibility of water. The following are some of the values obtained for the magnetic susceptibility of water by older and by more recent observers.

Observer.	Value of $k\,10^{-6}$ for water.
Faraday	0·72
E. Becquerel	0·67
P. Curie	0·79
Townsend...................	0·77
Quincke	0·81
Du Bois	0·84
Mean value =	0·77

Hence our value for water $0{\cdot}74 = k10^{-6}$ is not far from the mean of the above results.

Many other experiments were then made with various solutions of salts of iron and manganese, which satisfied us that we could place reliance upon the results of this method in measuring the magnetic susceptibility of a liquid, and we then proceeded to experiments with liquid oxygen.

The balls were accordingly all weighed in liquid oxygen contained in a vacuum vessel placed over the pole piece of the magnet. This vacuum vessel contained mercury in its vacuum space and was of an unusually excellent kind. In it liquid oxygen could be preserved for periods of many hours without a trace of ebullition, and no difficulty was experienced in making the weighings with great accuracy. These weighings of course served also to determine the density of the liquid oxygen used. The results are embodied in the following tables.

In each case the weighings give the apparent susceptibility of the liquid oxygen, and these figures have to be corrected by adding or subtracting a number representing the absolute susceptibility of the ball at the liquid oxygen temperature. Thus in the case of the silver ball the figure subtracted is two, as the nearest integer representing the susceptibility of silver at −182° C. In the case of the bismuth ball the figure subtracted is sixteen, in the case of the glass balls it is zero or at most unity, and in the case of the copper ball the correction is additive, depending on the value of the field.

Table V.—Determinations of the Magnetic Susceptibility of Liquid Oxygen.

I. *With the Silver Ball.*

Volume of ball = 12·684 c.c. at temperature of liquid oxygen.
Density of liquid oxygen = 1·1376.
Distance of centre of ball from pole of magnet = 5·37 cm.
Magnetic susceptibility of silver ball = $1·73 \times 10^{-6}$.

Exciting current by Weston ammeter, No. 3134.	Field. H.	Field variation, dH/dx.	Loss in weight of ball in grams., W.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
15	2218	408	3·7585	322	320
14·5	2174	400	3·6242	323	321
12	1950	359	2·8845	319	317
9	1646	302·5	2·0365	317	315
6	1242	228	1·2303	337	335
4	928	170·4	0·6855	336	334
3	723	132·7	0·4243	343	341

Mean value of susceptibility of liquid oxygen as determined with the silver ball = 326×10^{-6}.

II. *With the Bismuth Ball.*

Volume of ball at temperature of liquid oxygen = 6·287 c.c.
Density of liquid oxygen = 1·1397.
Distance of centre of ball from pole = 4·865 cm.
Magnetic susceptibility of bismuth ball = $13·75 \times 10^{-6}$ at 15° C.
" " " = $15·9 \times 10^{-6}$ at −182° C.

Exciting current by Weston ammeter.	Field.	Field variation.	Loss in weight of ball in grams.	Suscepti-bility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
12	2135	373	1·655	325	309
6	1356	236	0·705	344	328

Mean value of susceptibility of liquid oxygen as determined with the bismuth ball = 319×10^{-6}.

III. *With the Copper Ball.*

Volume of ball at temperature of liquid oxygen = 4·190 c.c.
Density of liquid oxygen = 1·140.
Distance of centre of ball from pole = 5·46 cm.
Magnetic susceptibility (varies from 8×10^{-6} to 15×10^{-6}).

Exciting current by Weston ammeter.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
6	1220	227	0·3721	315	323
5	1080	201	0·2930	316	325
4	911	169·5	0·2096	318	329
3	709	131·9	0·1282	321	333
2	470	87·4	0·0546	311	326

Mean value of susceptibility of liquid oxygen as determined with the copper ball = 327×10^{-6}.

IV. *With the Glass Ball No.* 1.

Volume of ball at temperature of liquid oxygen = 6·513 c.c.
Density of liquid oxygen = 1·1391.
Distance of centre of ball from pole = 4·96 cm.
Magnetic susceptibility of glass ball = $0·48 \times 10^{-6}$.

Exciting current by Weston ammeter.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k . 10^{-6}$.
7	1480	257	0·815	323	322·5
6	1330	231	0·671	329	328·5
3	777	134·9	0·229	329	328·5

Mean value of susceptibility of liquid oxygen as determined with the glass ball No. 1 = 326×10^{-6}.

V. *With the Glass Ball No.* 2.

Volume of ball at temperature of liquid oxygen = 1·456 c.c.
Magnetic susceptibility of ball = $0·024 \times 10^{-6}$.

Distance of ball from pole.	Exciting current of magnet.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k . 10^{-6}$.
4·57	14·5	2500	427·5	0·4919	310·1	310
	14·5	2500	427·5	0·4916	309·9	310
	13	2350	402	0·4333	309·1	309
	12	2240	383	0·3936	309·1	309
	12	2240	383	0·3947	310·0	310
	6	1422	236·5	0·1721	344·8	345
	6	1422	236·5	0·1723	345·2	345
7·04	12	1379	317	0·2260	348·4	348
	12	1379	317	0·2252	347·1	347
	6	865	215	0·0894	323·9	324
	6	865	215	0·0894	623·9	324

Mean value of susceptibility of liquid oxygen as determined with the glass ball No. 2 = 325×10^{-6}.

VI. *With the Glass Ball No. 4.*

Volume of ball at temperature of liquid oxygen = 0·5858 c.c.
Magnetic susceptibility of ball $= -1{\cdot}23 \times 10^{-6}$.

Distance of ball from pole.	Exciting current of magnet.	Field.	Field variation.	Loss in weight of ball in grams.	Apparent susceptibility, $k_1 10^{-6}$.	Absolute susceptibility of liquid oxygen, $k 10^{-6}$.
4·935	15	2392	437	0·1912	306	305
	15	2392	437	0·1902	305	304
	12	2102	384	0·1475	306	305
	6	1337	234	0·0628	336	335
	12	2102	384	0·1477	306·5	305
	6	1337	234	0·0620	332	331
4·115	12	2418	391	0·1795	318	317
	6	1532	238	0·0790	361	360

Mean value of susceptibility of liquid oxygen as determined with glass ball No. 4 $= 320 \times 10^{-6}$.

The absolute susceptibility is derived from the apparent susceptibility by adding or subtracting the susceptibility of the ball used according as it is paramagnetic or diamagnetic.

In the case of the copper ball, owing probably to traces of iron, the paramagnetic susceptibility is rather large and varies with the field. The proper additive correction was obtained by drawing a curve and setting off the observed values of the copper ball susceptibility as ordinates corresponding to the proper field strengths.

The mean value from all the six sets of observations comprising thirty-six determinations with the silver, copper, bismuth, and four glass balls is to give a value of 324×10^{-6} as the mean co-efficient of magnetic susceptibility of liquid oxygen. From the relation $\mu = 1 + 4\pi k$, the magnetic permeability can be deduced, and if $k = 324 \times 10^{-6}$ we have $\mu = 1{\cdot}0041$, as the value of the permeability of liquid oxygen.

The value of μ we gave (see 'Proc. Roy. Soc.,' vol. 60, p. 292) as the result of our former experiments by a totally different method was $\mu = 1{\cdot}00287$, or nearly, 1·003.

Hence these two methods agree in giving values of the magnetic permeability of liquid oxygen differing only by about one part in a thousand.

The results of the present work must, however, be taken as giving a much more probable value of the magnetic susceptibility.

On examining the above results it will be seen that there is a general tendency for the susceptibility with large fields of the order of 2500 to be less than the susceptibility for fields of the order of 500. The average susceptibility in fields of from 2500 to 1900 is more nearly 310×10^{-6}, and that in fields from 1100 to 500 more nearly 330×10^{-6}.

The difference only amounts to about 10 per cent. of the lower value, and it cannot be said that the observations are all of exactly equal weight.

The general result is to show that between the limits of $H = 500$ and $H = 2500$ the average magnetic susceptibility of liquid oxygen has a value which does not differ much from 324×10^{-6}, but with a small but decided tendency to decrease in strong fields.

The determination of the variation of susceptibility in much weaker fields is left undecided by these experiments, but by the employment of a torsion balance we hope to be able before long to give the ratios of the susceptibility in various fields much weaker than those employed in the foregoing experiments.

In connection with the determination of the absolute magnetic susceptibility of liquid oxygen, our attention has been much directed to the important matter of the determination of magnetic susceptibilities of substances in general at very low temperatures.

Having regard to the great loss in magnetic susceptibility experienced by the ferromagnetic metals in heating beyond a certain temperature, it has been frequently suggested that bodies of small susceptibility might become strongly magnetic if cooled to a sufficiently low temperature. Faraday made many experiments on this question, using solid carbonic acid as a refrigerating agent, but was not able to arrive at any conclusions.

A difficulty which presents itself in the use of liquid oxygen as a refrigerating agent for this purpose is the strongly magnetic quality of the liquid itself. All bodies except iron, nickel, and cobalt, and the strongly ferromagnetic bodies, become apparently diamagnetic when placed in liquid oxygen and in a non-uniform magnetic field.*

Moreover, for obvious reasons it is easy to weigh a diamagnetic or apparently diamagnetic body in a non-uniform field because the forces restoring the disturbed body to its original position increase with the displacement. If, however, an attempt is made to determine the force acting upon a paramagnetic body in a non-uniform field by a balance, the body weighed is in unstable equilibrium.

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* An interesting experiment was made with a ball of ebonite which illustrates this fact. Ebonite is slightly magnetic in air, owing no doubt to iron impurity. Ebonite is denser than liquid oxygen. Accordingly, a small ball of ebonite dropped into the liquid oxygen contained in the vacuum vessel of the pole of the magnet sunk to the bottom of the vessel. On exciting the magnet the ebonite became apparently strongly diamagnetic and was repelled by the pole. It floated up in the liquid until it reached a level at which the diamagnetic repulsion just balanced the apparent weight of the ball in the liquid oxygen. Instructive lecture experiments can be made in this manner.

We have only recently overcome these difficulties. The method we have adopted for cooling the body under test, is to suspend it freely near the bottom of a test-tube, which is placed in a vacuum vessel, the interspace between the two being filled with liquid air. In this way the body is cooled by radiation to the temperature of liquid air, and yet it is suspended in, and surrounded by, gaseous air, the magnetic susceptibility of which is exceedingly small compared with that of liquid oxygen or liquid air.

By limiting the vibration of the balance within small limits by the stops, or by gradually varying the field of the magnet with a carbon rheostat, until the field is just able to move the object from a standard position against the fixed restraining force supplied by a constant counter-balancing weight, we have been able to effect the measurements of the apparent weight of the tested object at a given distance from the pole, and in a known field, even though the equilibrium is not stable. In this way we have made preliminary experiments on the variation in the diamagnetic susceptibility of bismuth, and of the paramagnetic susceptibility of manganous sulphate in the solid condition.

We made a preliminary experiment by weighing in and out of the magnetic field a small closed glass bulb, exhausted of its air both when in ordinary air at the normal pressure and temperature, and then suspended on the dense gaseous air in the inner test-tube, which is at a temperature of −182° C. lying at the bottom of the inner test-tube, placed as above described in a vacuum vessel. We found the magnetic susceptibility of the dense air at −182° C. to be $+0·28 \times 10^{-6}$, in other words about 10 times the susceptibility of air at the normal temperature and pressure. This number 0·28 is quite insignificant compared with numbers of the order of 100 or 300. Hence an object suspended in the above described manner, can be reduced to the temperature of liquid air without changing the susceptibility of the surrounding medium by an amount which is at all comparable either with that of liquid oxygen, or with the value of the susceptibility of bismuth, or of most paramagnetic bodies such as the salts of iron, nickel, cobalt, manganese, or of palladium, or any of the strongly paramagnetic bodies.

In this manner we have made a determination of the change in paramagnetic susceptibility of crystallised manganous sulphate in the form of powder.

We find that the susceptibility of the salt at 25° C. is to that at −182° C. in the ratio of 105 to 349 or 1 to 3·32.

These centigrade temperatures, 25° C. and −182° C , correspond to

298 and 91 on the absolute thermometric scale, and it is obvious therefore that the paramagnetic susceptibility of solid manganous sulphate is increased by cooling so that its value varies *inversely as the absolute temperature, and is increased threefold by cooling to the temperature of liquid oxygen.*

It has been shown by P. Curie, that the above law holds good for oxygen, palladium and other paramagnetic bodies at high temperatures; and E. Wiedemann (Pogg. Ann., vol. 126, p. 1, 1885) and Plessner (Wied. Ann., vol. 39, p. 336, 1890) have shown that for limited ranges of temperature, 16° to 60°, it is true for paramagnetic salts in the liquid and solid condition.

Our experiments show that this law may be valid over very wide limits, and to very low temperatures. We hope to fully examine this matter shortly, and to make a full examination of paramagnetic susceptibility at very low temperatures.

We have also made measurements of the magnetic susceptibility of bismuth at the liquid oxygen temperature.

From the mean of three experiments, we find that the diamagnetic susceptibility of bismuth is increased by cooling, and that it has the following values:—

Diamagnetic susceptibility of bismuth at 15° C. = 13·7,
" " " −182° C. = 15·9,

thus showing an increase of 16 per cent. on the lower value.

The diamagnetic susceptibility of bismuth is therefore not increased inversely as the absolute temperature on cooling.

The above considerations suggest that the very large paramagnetic susceptibility of liquid oxygen, which is five or six times greater than that of a saturated solution of ferric chloride, may in part be due to its low temperature.

Some experiments we have made on the susceptibility of manganous sulphate indicate that paramagnetic susceptibility varies directly as the density.

The density of liquid oxygen is 806 times that of gaseous oxygen at 0° C. and 760 mm., and its absolute temperature is just one-third.

Hence if the law that susceptibility varies as the density and inversely as the absolute temperature holds good down to the temperature of −182° C., and over the physical change of state, we should expect the susceptibility of the liquid oxygen to be 2418 (= 806 × 3) times that of the gas.

The magnetic susceptibility of gaseous oxygen as determined by Faraday, E. Becquerel, and others is $0{\cdot}13 \times 10^{-6}$. Now $2418 \times 0{\cdot}13 \times 10^{-6} = 314 \times 10^{-6}$.

The mean value we have found for the susceptibility of liquid oxygen is 324×10^{-6}, and many of our values for it are exactly 314×10^{-6}.

It seems therefore possible that for paramagnetic bodies over wide limits of density and temperature we may find that the magnetic susceptibility varies directly as the density and inversely as the absolute temperature.

We desire to add that our thanks are due to Mr. J. E. Petavel and Mr. J. T. Morris, for their assistance in carefully carrying out the tedious work of the ballistic observations, necessary to determine the field of the electro-magnet we have used.

"Aluminium as an Electrode in Cells for Direct and Alternate Currents." By E. WILSON. Communicated by Dr. J. HOPKINSON, F.R.S. Received May 11,—Read May 26, 1898.

This paper deals with the apparent great resistance which aluminium offers to the passage of an electric current when used as an anode in cells containing, for instance, such an electrolyte as alum in water. The following are references to papers which deal in whole or in part with this or other properties of aluminium when employed as an electrode in electric cells.

Wheatstone. 'Roy. Soc. Proc.' Read April 26, 1855. This is the earliest paper I have found dealing with the metal aluminium in voltaic cells, but Wheatstone does not appear to have noticed the apparent great resistance mentioned above.

Heeren. 'Mittheil. des Gewerbevereins für Hannover,' Jahrg. 1855, p. 342. Reference is made in this paper to Wheatstone's experiments.

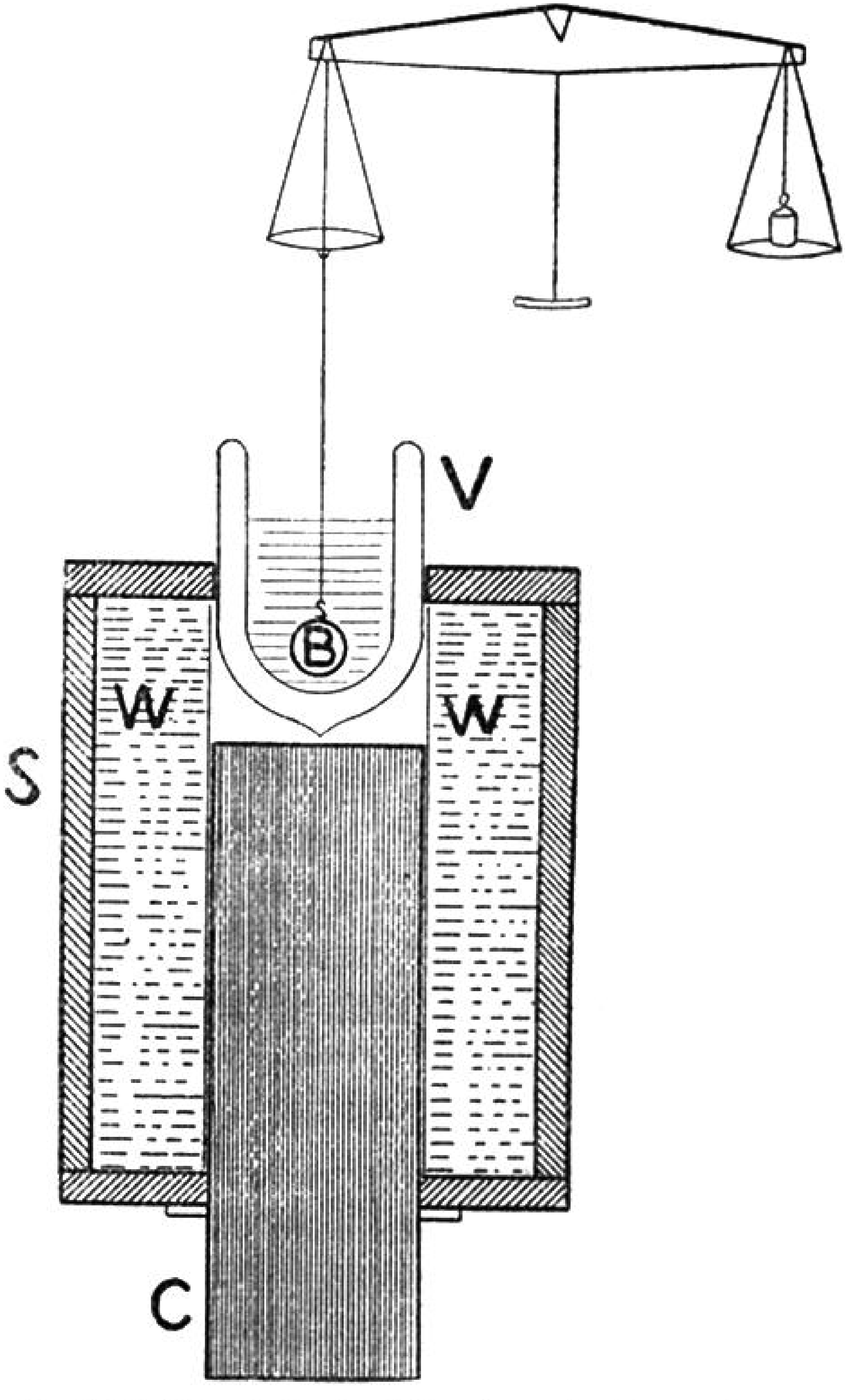
Buff. 'Liebig's Annalen,' 1857, vol. 102, p. 269. The author of this paper points out that nine Bunsen elements were not able to pass a current through a cell having aluminium as an electrode. This is the first mention of this property I can find.

Ducretet. 'Comptes Rendus,' 1875, vol. 80, p. 280; also 'Journ. de Phys.,' 1875, vol. 4, p. 84. Observed great resistance in dilute sulphuric acid due to aluminium plate.

Beetz. 'Wied. Ann.,' 1877, vol. 2, p. 94. Supposes oxygen to be the cause of this apparent high resistance.

Winkelmann. 'Wied Ann.,' 1883, vol. 20, p. 91.

Wright and *C. Thompson.* 'Phil. Mag.,' 1885, Part 9, Series 5, vol. 19, pp. 27, 116, 203. Call attention to the non-compliance of aluminium with thermochemical data. Reference is made to the work of Julius Thomsen.



V, vacuum vessel ; B, ball weighed ; W, wire windings of magnet ; S, C, steel shell and magnet core.